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TECHNICAL REPORT ARCCB-TR-88041

FRACTOGRAPHIC ANALYSIS OF A FAILED CRANE BOLT

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NOVEMBER 1988

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1. REPORT NUMBER ARCCB-TR-88041	2. GOVT ACCESSION NO. A203 703	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FRACTOGRAPHIC ANALYSIS OF A FAILED CRANE BOLT		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. A. Kapusta		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army ARDEC Benet Laboratories, SMCAR-CCB-TL Watervliet, NY 12189-4050		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 6126.23.1BLO.OAR PRON No. 1A92ZNACNMSC
11. CONTROLLING OFFICE NAME AND ADDRESS US Army ARDEC Close Combat Armaments Center Picatinny Arsenal, NJ 07806-5000		12. REPORT DATE November 1988
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Failure Analysis
Fractography
Fatigue

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A failed crane bolt was examined by scanning electron microscopy to determine its failure mode. Failure occurred by fatigue crack initiation at the root of a thread with subsequent propagation by fatigue through essentially the entire ~ 0.7-inch diameter cross section of the bolt.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

A section of a failed bolt was received for fractographic analysis to determine its failure mode. The bolt was from a p duction crane at the Watervliet Arsenal, reportedly installed prior to World War II. The purpose of this investigation was to examine the failure mode of the bolt for safety and other reasons.

FRACTOGRAPHIC ANALYSIS

The as-received bolt section measured approximately 1.2 inches long by approximately 0.87 inch in diameter in the unthreaded shank and about 0.7 inch in diameter at the base of the threads.

Fracture had initiated in the root of the second thread from the shank and had propagated across the entire ~ 0.7-inch diameter cross section. The fracture surface was essentially flat and transverse to the axial dimension of the bolt except for a very small (<< 1 percent of the fracture area) region which most likely represents final overload separation. This (transverse) fracture plane orientation is consistent with the plane of maximum normal stress that would be induced by axial tensile and/or bending loading of the bolt. The fracture region did not show macroscopic (gross) deformation, so in this sense the separation could be considered "brittle." However, after cleaning the fracture surface by dry-stripping plastic replicas, it displayed a dull, matte appearance, indicative of a microscopically ductile separation. Microscopically ductile fracture would be limited to microvoid initiation/coalescence (dimples) and/or stage II fatigue. A modified form of dimpled rupture, sometimes called "low energy tear," would also tend to show a dull, matte macroscopic appearance.

A microscopically brittle separation, on the other hand, would tend to show a specular, faceted fracture appearance (as opposed to matte) indicative of transgranular cleavage and/or intergranular decohesion.

Viewing the fracture surface under oblique illumination revealed faint beach marks shown in Figure 1, indicative of initiation from a single site.

The cleaned fracture surface did not contain gross (thick) oxide or corrosion products. Also, the fracture showed no evidence of gross post-fracture mechanical smearing or pounding of the mating fracture surfaces which, if present, would be indicative of a compressive or shear component of loading. The fracture surface, therefore, is consistent with tension-tension loading.

Energy dispersive x-ray (EDX) analysis and scanning electron micrographs (SEM) were taken from selected areas along the fracture surface as noted in Figure 1.

RESULTS

An EDX spectrum, Figure 2, from a "clean" cut surface of the bolt shows that it is made from plain steel.

SEM, Figure 3, shows the initiation region, while Figure 4, at higher magnification shows this region to be free of any material defect. The fracture surface was essentially transgranular (Figures 4, 5, and 7), and stage II fatigue striations were found across its entire length (Figures 4a, 4b, 6, and 7a), except for the very small region labeled in Figure 1. This small region was all transgranular dimpled (Figure 8a) consistent with and indicative of final fast overload fracture. Most of these dimples were equiaxed, indicative of a mode I tensile separation. Fatigue crack growth direction, determined from striation orientation, was consistent with crack initiation from a single site and subsequent propagation as noted in Figure 1.

Striation density was fairly constant across the fracture, yielding an estimated 50×10^3 cycles accrued after initiation on the ~ 0.7-inch diameter cross section.

Of the several empirically derived fatigue crack growth rate (FCGR) versus ΔK relationships in the literature, that shown in Figure 9 (ref 1) is relevant to this sample, since it was derived for ferrite/pearlite steels. Using the crack growth versus stress intensity plot in Figure 9, a ΔK of ~ 34 $\mathrm{Ksi}\sqrt{\mathrm{in.}}$ was derived for this bolt.

The fracture surface revealed only a minimal amount of non-metallic inclusions, i.e., the material appeared quite "clean," at least in this fracture plane.

CONCLUSIONS

1. The bolt failed due to cyclic fatigue loading rather than single cycle overload.

2. The fracture plane orientation is consistent with the plane of maximum normal stresses which would be induced by axial tension and/or bending of the bolt. Crack initiation at only one site and the observed crack growth direction indicate that the bolt most likely had been loaded in bending, as opposed to axial tension.

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[1] S. T. Rolfe and J. M. Barsom, Fracture and Fatigue Control in Structures, Prentice-Hall, Inc., Englewood Cliffs, NJ, p. 239.

3. There was no evidence of material defect(s) or of any overload tearing at the initiation which could have started a fatigue crack.

4. Estimates of the acting ΔK were made using the measured da/dN from the micrographs and FCGR-ΔK relationships in the literature for ferrite/pearlite steels. The acting ΔK for this ferrite/pearlite bolt, from Figure 9, was calculated to be ~ 34 Ksi$\sqrt{in}$.

5. The material appears to be free of any gross amount of large non-metallic inclusions, at least in this fracture plane.

6. The microscopically ductile fatigue and final overload separation indicate that the material has probably not been embrittled during its service life. The fracture mode in both the fatigue and final overload regions was transgranular.

7. The absence of any thick oxide and/or corrosion product indicates that the fracture had occurred in a non-aggressive environment.

REFERENCES

1. S. T. Rolfe and J. M. Barsom, Fracture and Fatigue Control in Structures, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1977, p. 239.

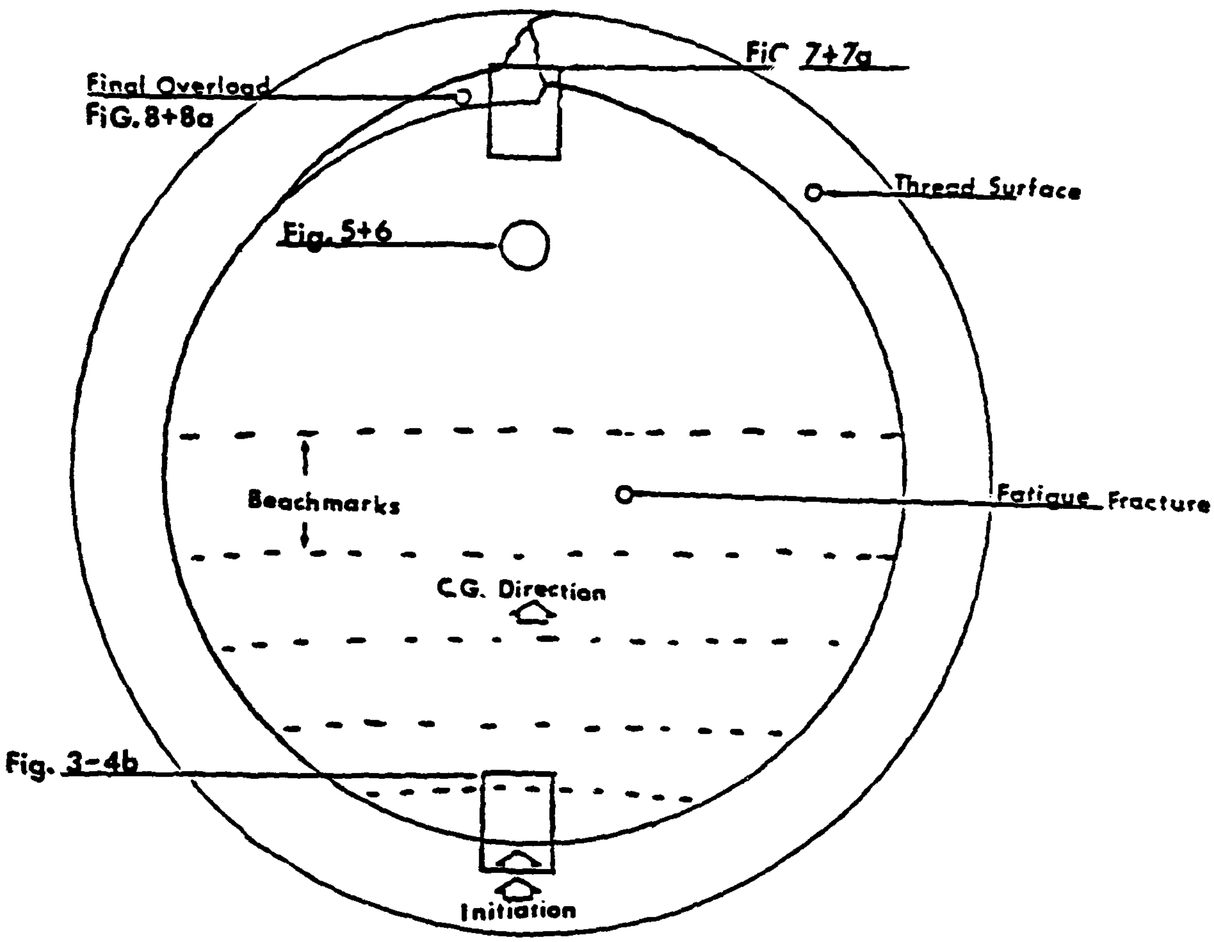

Figure 1. Schematic of fracture surface.

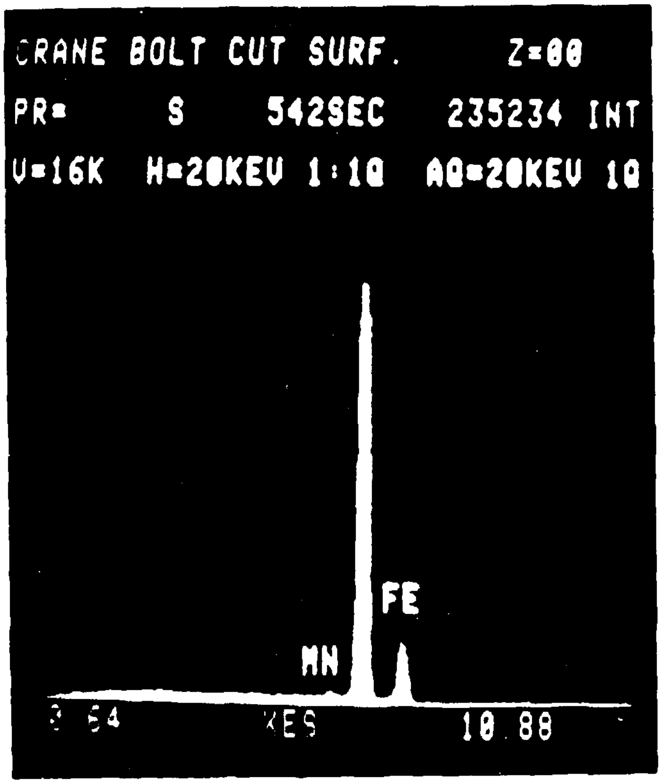

Figure 2. Energy dispersive x-ray spectrum of crane bolt.

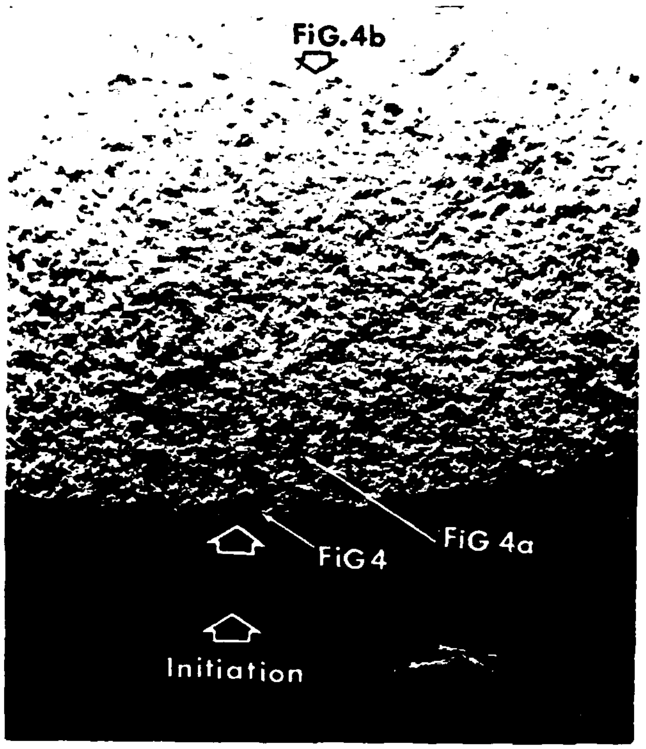

Figure 3. Fatigue fracture initiation as indicated by the white arrow (12X).

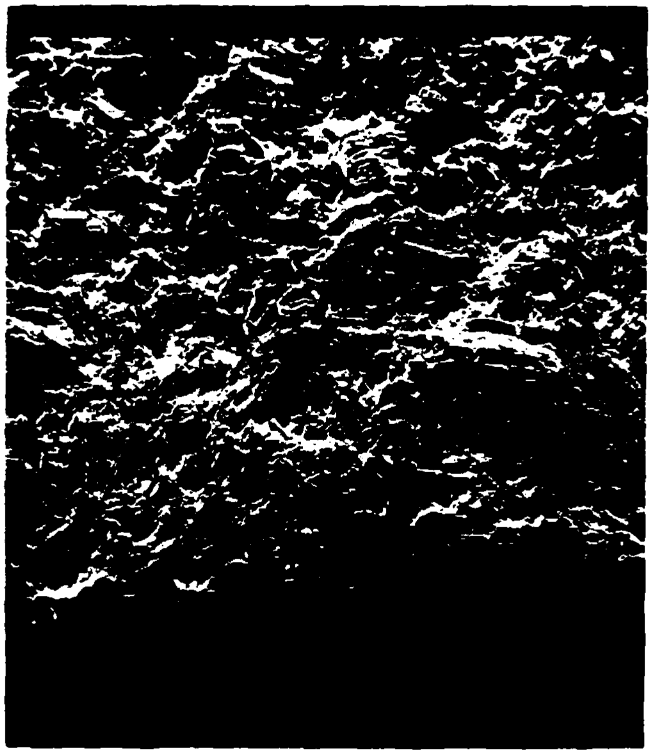

Figure 4

Figure 4a

Figure 4b

Figure 4. Transgranular fracture at initiation (100X).
(a) and (b) show fatigue striations (3300X).

Figure 5. Fatigue fracture propagation (55X).

Figure 6. Fatigue fracture propagation at a higher magnification (1500X).

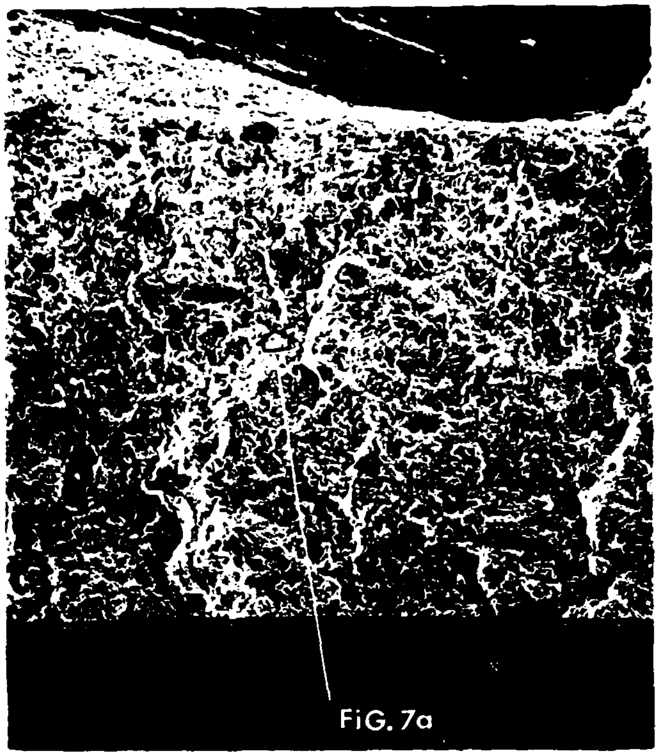

Figure 7. Fatigue fracture propagation (30X).

Figure 7a. Fatigue striations (2000X).

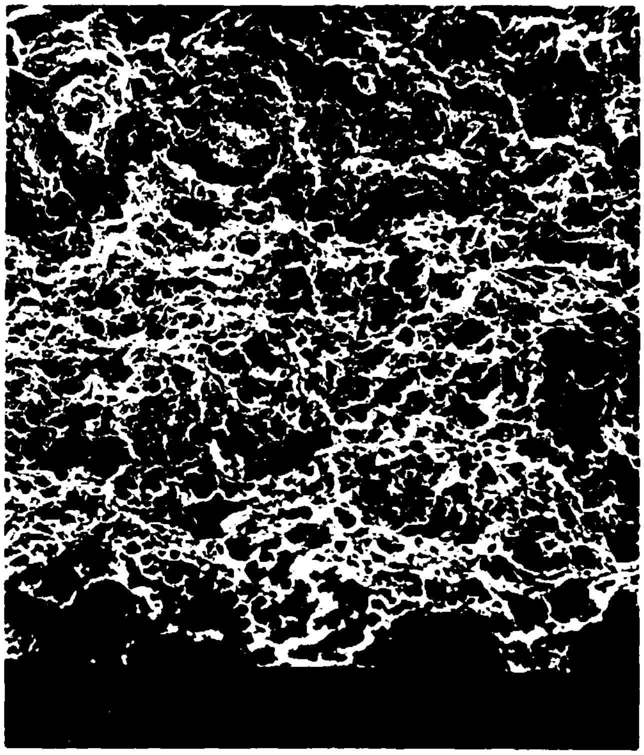

Figure 8. Final tensile overload separation (100X).

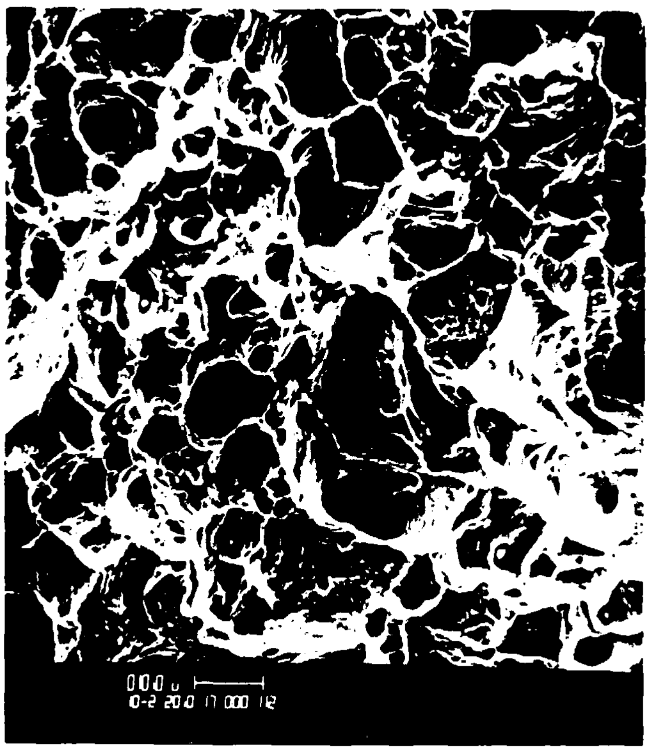

Figure 8a. Microvoid mode of fracture in final tensile overload (1000X).

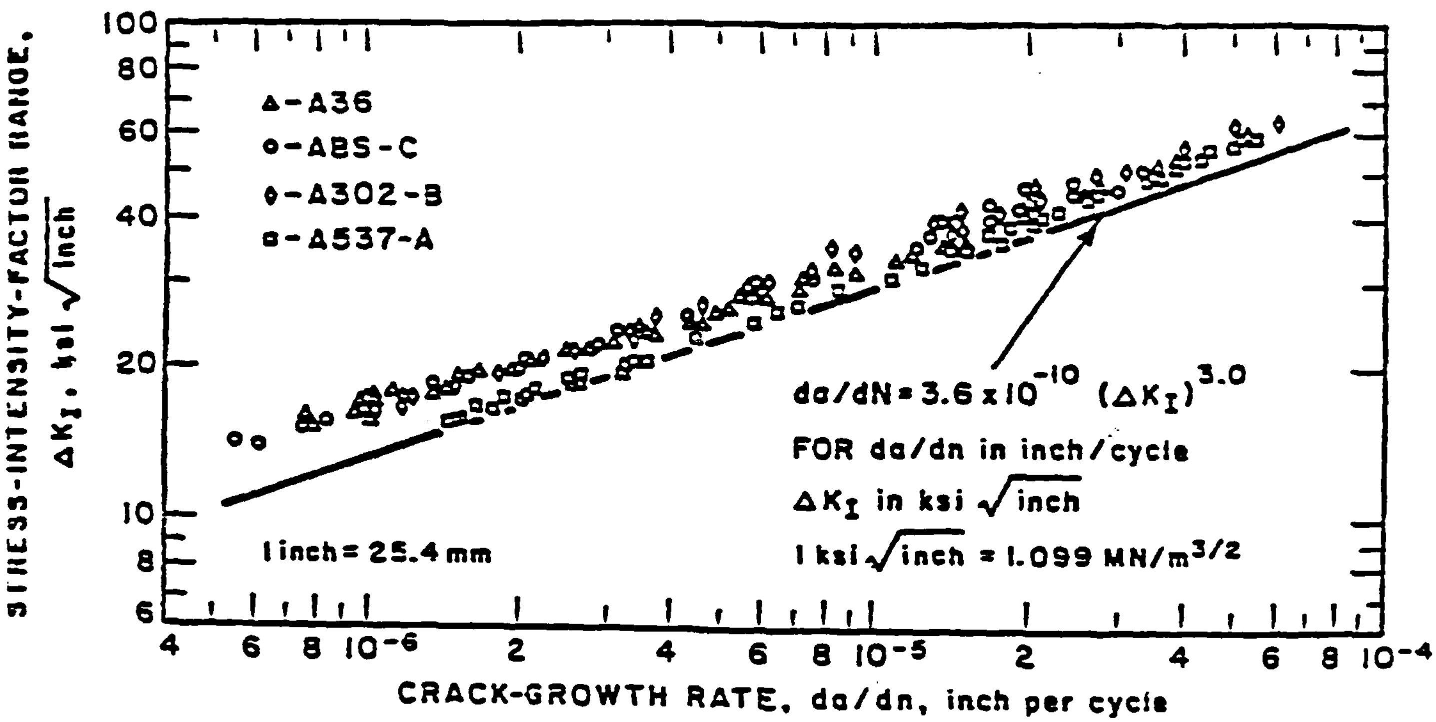

Figure 9. Fatigue crack growth data for pearlitic/ferritic steels (ref 1).

Rolfe/Barsom, FRACTURE AND FATIGUE CONTROL IN STRUCTURES: Applications of Fracture Mechanics, © 1977, p. 239. Reproduced by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

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